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SEED TREATMENTS AND GENETIC RESISTANCE FOR CONTROLLING SMUT DISEASES IN WINTER WHEAT

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INTRODUCTION

Smuts were the most destructive diseases of winter wheat in the Pacific Northwest (PNW) until 1956 (Shafer, 1987). Until that time the major emphasis of wheat breeding programs was developing smut-resistant varieties (Hoffmann, 1982). Unfortunately, the pathogens quickly evolved to overcome the resistance of each newly released variety. Fungicide seed treatments (formaldehyde, copper carbonate, and organic mercuries) that were effective in other regions or countries failed to control common bunt (*Tilletia caries*), dwarf bunt (*T. controversa*) and flag smut (*Urocystis agropyri*) because, in the semiarid PNW, spores of the pathogens persisted in soil as well as on seed. Loose smut (*Ustilago tritici*) was not amenable to control by chemical seed treatment because the pathogen was protected within infected seeds.

Soilborne inoculum of the smut pathogens was not controlled by chemical seed treatments until the advent of the polychlorophenols, particularly hexachlorobenzene (HCB) and pentachloronitrobenzene (PCNB), in the mid-1950's. Seed treatment technology for smut control was advanced markedly when TBZ (thiabendazole) and Vitavax (carboxin) were registered in the 1960's. These were the first systemically translocated fungicides and they greatly improved the control of most smut diseases, including loose smut. Neither fungicide is completely effective against soilborne inoculum of the common bunt pathogen at recommended application rates (Gaudet et al., 1989). However, during the past two decades approximately 95 percent of winter wheat seed planted in the PNW has been treated with Vitavax. Combination of seed treatment and resistant host variety, each of which provide incomplete control, have been utilized as an effective integrated control strategy that virtually eliminated economic damage from all except dwarf bunt.

Near freedom from common bunt and an emerging crisis with stripe rust caused breeders to reduce emphasis on common bunt. Numbers of pathologists and geneticists specializing in smuts of wheat in the PNW have declined from nine to zero during the past three decades. Some of the new winter wheat varieties in the PNW are susceptible to all smut pathogens. The hazard of placing excess emphasis on fungicides was clearly defined in Europe by the development of races of the common bunt pathogen resistant to HCB (Kuiper, 1965). Outbreaks of the disease occurred shortly after the fungicide defense was breached. The barley loose smut pathogen also developed tolerance to carboxin in several European countries during the 1980's (Brent, 1988; Leroux and Berthier, 1988). Experiences in several regions of the world indicate that when reliance is shifted too heavily toward chemical treatments, and away from development of resistant varieties, many fungicides ultimately fail, requiring a renewed emphasis on breeding resistant varieties and on development of new fungicides. Combining chemical control with genetic resistance usually prevents the failure of either component of the dual-control system.

Winter wheat varieties lacking genetic resistance to these diseases are once again being released in the PNW. That presents a challenge for disease management specialists because smut pathogens are still present in soil at threatening levels (Hoffmann, 1982; Hoffmann and Waldher, 1981). One or more smut diseases are observed on a small percentage of winter wheat plants every year, apparently because the critical amount of fungicide does not adhere uniformly to all seeds during treatment. In Oklahoma, during a period of drier-than-normal summers, common bunt reappeared suddenly even though it had been nearly non-existant for 40 years and Vitavax was being used (Williams, 1990). PCNB seed treatment and a series of wetter summers (normal) brought the outbreak under control. There does not appear to be any evidence that the pathogen had become tolerant of Vitavax in Oklahoma.

Although tolerance to Vitavax also does not appear to have occurred among smut pathogens in the PNW, fungicides unrelated to Vitavax and a return to the dual-control strategy are clearly needed to assure the stability of the wheat industry. In 1990 and 1991, for instance, a Umatilla County producer who grew a flag smut-susceptible variety without seed treatment for two successive years in a winter wheat-summer fallow rotation experienced 50 and 19 percent yield reductions due to flag smut during the second crop on each field of the rotation (Karow et al., 1994; Smiley and Uddin, 1992). A seed treatment is also needed to supplement the incomplete host resistance available for controlling dwarf bunt, the disease that prevents export of PNW wheat to the People's Republic of China.

Several new triazole-derivative fungicides have been registered during the past decade. They are systemically translocated in plants, have broad spectrum of fungitoxicity, and varying degrees of plant growth regulating activity. Baytan (triadimenol) was the first triazole fungicide to be used as a translocated seed treatment (Buchenauer and Grossman, 1977; Frohberger, 1978). Plant growth regulatory (phytotoxic?) effects of Baytan include delayed emergence, reduced surface area of coleoptiles, growth retardation, reduced root length and tillering aberrations (Buchenauer and Rohner, 1981; Fletcher and Hofstra, 1985; Forster et al., 1980; Gao et al., 1988; Monfort et al, 1995; Smiley et al., 1990). Baytan provides excellent protection against smuts when used at recommended rates and with shallow planting depth. It is not recommended for use with deep-furrow drills.

Dividend (difenoconazole), registered in 1994, is a triazole fungicide that recently gained attention because of its ability to control dwarf bunt (Sitton et al., 1994) and other smuts. The influence of Dividend on seedling emergence, grain yield, and farm profitability have not been reported. Of particular interest was whether Dividend, as with many other new fungicides, will be limited to a niche market to control dwarf bunt, or whether it has characteristics enabling it to become the primary seed treatment for general use throughout the PNW?

The objectives of this study were to review the status of fungicide seed treatments currently available for controlling smuts, review smut disease reactions for currently recommended winter wheat varieties, and investigate comparative effects of Dividend and Vitavax on winter wheat seedling emergence and development, grain yield, test weight, and profitability.

METHODS

Status of Fungicide Seed Treatments for Smut Diseases

The 1994 and 1995 “Pacific Northwest Plant Disease Control Handbooks” were used to determine current recommendations for seed treatments on winter wheat. Reports in the technical literature were also examined.

Status of Varietal Resistance to Smuts

Levels of resistance or susceptibility to smut diseases of winter wheat varieties were determined from the publications "Winter Cereal Varieties for 1994" (from Oregon State University) and "1994 Certified Seed Buying Guide" (from the Washington State Crop Improvement Association). When rating discrepancies were reported for a single variety the most susceptible of the ratings was used for assessments in this paper. Many races of each pathogen exist in the PNW and regional differences occur for susceptibility of a given variety.

Grain Yield and Test Weight

Comparisons of Dividend 3FS (0.25-1.0 fl oz/cwt) and either Vitavax 200F (3-4 fl oz/cwt) or RTU Vitavax Thiram (4-5 fl oz/cwt), or neither, were made in 24 experiments performed over five years (1990-1994 crops) at 12 eastern Oregon and Washington sites using seven winter wheat varieties. These experiments resulted in as many as 44 comparisons of yields among treatments for individual varieties, locations and years.

Most (16 of 24) tests were conducted in commercial fields. One experiment (at Echo) was located in an annually cropped irrigated field and others were in non-irrigated winter wheat-summer fallow rotations in 11- to 20-inch rainfall zones. All sites except Prosser, WA (Horse Heaven Hills area) were in Oregon. Soils, planting dates and depths, mean annual precipitation, and soil temperature at planting depth for each location are presented in Table 1.

Seed was planted with a Hege plot drill, at six seeds/foot of row (75-80 pounds/acre, depending on seed size). All tillage, fertilizer and weed management procedures were in accordance with commercial practices. Experiments were randomized complete block designs with five replications per treatment. Plots measured 5 x 20 feet and contained 5 rows spaced at 12-inch intervals. Plots were harvested with a Hege plot combine and grain samples were cleaned before determining grain yield, test weight, and kernel weight.

Data was analyzed by conducting an analysis of variance on the maximum number of tests in which each variable (fungicide treatment and/or rate) of interest occurred. That data were also evaluated by grouping tests that included a single variety, and by grouping tests according to yield brackets (10-bushel intervals) for grain produced from untreated seed.

Profitability

Summarized yield data from experiments described above was used to determine profitability of seed treatments. Other values used in the calculations were planting rate (80 lb seed/acre), income from grain produced ($3.50/bushel), grain test weight (60 pound/bushel), and costs for Dividend

Table 1. Characteristics of 12 locations where seed treatments were evaluated for effects on seedling emergence and grain yield from 1990 to 1994.

Location and number of tests	Soil series and texture†	Annual precip-itation (in.)	Planting dates	Planting depth inches	Planting depth temp. (°F)
Arlington - 4	Walla Walla	11	Sep 9-18	3-4	72-74
Dufur - 2	Wamic	14	Sep 9	2.5	61
Echo - 1	Shano	10	Oct 29	1.5	70
Elgin - 4	Palouse	20	Sep 12	1.5	67
Flora - 6	Cowsly	20	Sep 12-22	1.5	52-61
Haines - 1	Hutchison	14	Sep 12	1.5-3	65
Helix - 3	Walla Walla	15	Sep 13	3.5	78
Heppner - 6	Valby	14	Sep 10-18	3	73
Moro - 5	Walla Walla	12	Sep 9-18	2-4	68-75
Pendleton - 9	Walla Walla	16	Sep 11-20	3	73-75
Prosser - 2	Ritzville	11	Sep 2	5	74
Reith - 1	Walla Walla	15	Sep 18	5	75

† All soils were silt loams except for Wamic loam at Dufur.

($565.00/gallon), and RTU Vitavax Thiram ($32.50/gallon).

Seedling Emergence and Development

Seedling emergence was estimated at six sites during the 1993-1994 winter wheat season and at two sites during 1994-1995. Three sites each were selected to represent areas where standard planting depths during September are either shallow or deep (Table 1). Deep plantings (>3 inch) were in areas where rainfall is traditionally marginal and summer fallow consists of a deep mulch of dust plus residue. All seed preparation and planting procedures were as described for yield trials. Seedling emergence was monitored at 2- to 7-day intervals depending on the depth of planting and rate of seedling emergence. A qualitative emergence scale (0-3) was used in view of the large number of plots, distance between plots, and frequency of observation. Ratings were as follows: 0 = <10% seedlings emerged, 1 = 10-50%, 2 = 50-85%, and 3 = >85%. Plant height and tillers or heads per foot of row were evaluated at maturity. During 1994-1995, emergence was monitored only at two very dry sites where soil moisture at planting depth (5-7 percent) was inadequate for optimal seedling emergence.

RESULTS AND DISCUSSION

Status of Fungicide Seed Treatments for Controlling Smut Diseases

Seedborne inoculum of most smut pathogens is killed by Captan, Vitavax (carboxin), Dividend (difenoconazole), Mancozeb, PCNB (pentachloronitrobenzene), TBZ (thiabendazole), Thiram, and Baytan (triadimenol). In contrast, very few fungicides are completely effective for controlling soilborne inoculum. The list of recommended products ("1994 Pacific Northwest Plant Disease Control Handbook") for preventing disease from soilborne inoculum in the Pacific Northwest includes only Baytan, Dividend, PCNB, and TBZ. Loose smut is controlled only by the systemic fungicides Baytan, Dividend, TBZ, and Vitavax. Baytan is not recommended for deep-furrow planting systems because it tends to reduce the rate of internode elongation, which can adversely affect seedling emergence. At least one smut pathogen has developed tolerance to Baytan, TBZ, or Vitavax elsewhere in the world. There is a clearly defined need for at least two primary seed treatment fungicides to minimize the potential for an outbreak of a smut disease should tolerance to one fungicide be developed in the PNW.

Status of Variety Resistance to Smuts

For the purposes of this report there is no distinction made between susceptible or moderately susceptible varieties; all are considered susceptible in our summary. A variety is also considered susceptible if reported as such in either Oregon or Washington. Most (80-90 percent) soft white common, club, and hard red winter wheat varieties recommended for production in Oregon and Washington are susceptible to dwarf bunt and flag smut (Tables 2 and 3). Information is not available for loose smut. Many (32 percent) varieties are also susceptible to common bunt and differences in ratings occur among varieties released by public or private breeders in the two states. No varieties released by private breeders are apparently susceptible to common bunt. Six of eight varieties of soft white common wheat from Oregon are reported susceptible to common bunt (Table 2) and one of ten released from Washington (WSU and USDA-ARS) is susceptible (Table 3). Only one of seven hard red wheat varieties is susceptible and it was released by Oregon. Three of nine club wheat varieties are susceptible and all were released from Washington.

Grain Yield and Test Weight

Productivity of winter wheat varied from 20 to 100 bushel/acre (Table 4), reflecting a diversity of conditions under which fungicides were compared. Experimental locations were selected to examine seed treatments in areas where at least nine diseases or disease complexes were present. Diseases and other conditions affecting yield, such as drought or Hessian fly, were reported annually for each variety and fungicide treatment from 1991 to 1994 (*Fungicide and Nematicide Tests* volumes 47-50 [1992-1995]; American Phytopathological Society, St. Paul, MN), and are summarized in Table 4. Nearly half the comparisons in these studies involved situations where yield and response to fungicides was prevented by drought, disease-resistant varieties, or diseases against which the fungicides were not expected to be active. These tests provided a conservative measure of benefits likely to be experienced from use of seed treatments in commercial practice.

Table 2. Smut disease reactions for winter wheat varieties developed by public institutions in Oregon or private companies in the Pacific Northwest.

Release Year	Wheat Class and Variety	Common Bunt	Dwarf Bunt	Flag Smut
	Oregon Soft White Common			
1969	Yamhill	S	S	MS
1977	Stephens	R (S)	S	MS
1981	Hill	R (S)	S	MS
1987	Malcolm	R	S	MS
1987	Oveson	MR	S	MS
1991	Gene	S	S	MS
1992	MacVicar	S	S	-
1992	W301	MS	MS	MR
	Oregon Club			
1965	Moro	R	MR	MR
1976	Faro	MR	S	S
1992	Rohde	MR	S	(VS)
	Oregon Hard Red			
1991	Hoff	S	S	S
	Private-release Soft White Common			
1985	Basin	R	MR (S)	R (MS)
1985	Cashup	R	S	R (MS)
1991	Durheim's Pride	-	(S)	(MS)
1994	Banner	-	(S)	-
	Private-release Club			
1978	Jacmar	MR	MR	MR

† Disease reaction data are from the following publications: "Winter Cereal Varieties for 1994" (from Oregon State University) and "1994 Certified Seed Buying Guide" (from the Washington State Crop Improvement Association); VS = very susceptible, S = susceptible, MS = moderately susceptible, MR = moderately resistant, R = resistant. When discrepancies occur, or a rating was not provided in the Oregon guide, ratings from Washington were placed in parenthesis.

Table 3. Smut disease reactions for Washington public-release winter wheat varieties.

Release Year	Wheat Class and Variety	Common Bunt	Dwarf Bunt	Flag Smut
	Soft White Common			
1961	NuGaines	R	S	-
1973	Sprague	R (S)	S	MS
1976	Daws (USDA)	R	S	MS
1982	Lewjain (USDA)	R	MR	MS
1984	John	MR	S	MS
1985	Dusty	R	S	MS
1988	Madsen (USDA)	R	S	MS
1990	Eltan (USDA)	R	R (MR)	(MS)
1990	Kmor (USDA)	R	S (MR)	(MS)
1992	Rod (USDA)	R	S	(MS)
	Club			
1979	Tyee (USDA)	MR	S	VS
1982	Crew (USDA)	R	S	S
1984	Tres (USDA)	MS	S	VS
1988	Hyak (USDA)	MS	S	S
1990	Rely (USDA)	MS	S	VS
	Hard Red			
1965	Wanser	R	S	VR
1979	Hatton	MR	S	R
1979	Weston (USDA)	R	R	R
1985	Batum (USDA)	R	S	MS (R)
1987	Andrews	R	MR	R
1989	Buchanan	MR	S	R

† Disease reaction data are from the following publications: "Winter Cereal Varieties for 1994" (from Oregon State University) and "1994 Certified Seed Buying Guide" (from the Washington State Crop Improvement Association); VS = very susceptible, S = susceptible, MS = moderately susceptible, MR = moderately resistant, R = resistant. When discrepancies occur, or a rating was not provided in the Oregon guide, ratings from Washington were placed in parenthesis.

Table 4. Yield (bu/ac) and principal yield constraint for seven winter wheat varieties grown from seed treated with Dividend, Vitavax 200 (or RTU Vitavax Thiram), or untreated, in 24 experiments over five years at 12 Oregon and Washington locations.

		Main yield		Seed Treatment (fl oz/cwt)				
				Dividend			Vitavax	None
Crop Year	Location	con-straint	Wheat variety	0.25-0.33	0.5	1.0	4-5(RTU) 3-4(200)	
1990	Elgin	RR	Hill	69.2	68.1	73.3		69.3
			Lewjain	73.2	57.2	53.7		65.3
1990	Moro	CR	Stephens	35.5	36.0	35.5	-----	32.2
1990	Pendleton	N	Hill	61.8	63.8	61.3	-----	58.0
			Lewjain	67.4	70.4	63.3	-----	66.4
1991	Elgin	RR	Hill	76.9	74.6	69.8	77.2	66.1
			Lewjain	75.2	72.6	73.7	79.4	71.6
1991	Flora	DB,	Hill	81.2	87.6	84.9	73.7	69.8
		SM	Lewjain	76.3	79.4	88.8	75.3	71.6
1991	Haines	RR	Hill	63.2	66.1	73.0	59.9	71.5
1991	Echo	TA	Stephens	60.8	65.5	59.2	-----	62.5
1991	Reith	FS	Tres	32.7	38.2	33.9	29.0	21.3
1992	Arlington	CR	Stephens	-----	53.7	-----	52.8	50.1
1992	Flora	DB,	Hill	68.7	69.2	69.0	70.8	73.1
		SM	Lewjain	68.7	77.3	73.2	66.9	69.9
1992	Heppner	CS,	Lewjain	----- -	21.9	-----	17.1	.20.8
		D	Madsen	---- --	21.9	-----	..21.5	22.6
			Stephens	---	24.6	-----	20.8	21.5
1992	Moro	CR	Stephens	-----	69.5	-----	62.4	62.7
1992	Pendleton	FR	Lewjain	----- -	62.4	-----	.57.6 .	60.8
			Madsen	---- --	82.7	-----	.80.4 .	82.1
			Stephens	---	74.7	-----	.62.4..	64.4
1993	Arlington	CR	Stephens	-----	49.5	62.6	48.9.	47.4
1993	Flora	DB,	Hill	69.5	70.2	68.2	.73.3 .	63.6
		SR	Lewjain	66.4	72.6	67.8	.74.8..	57.3

Table 4. (continued)

1993	Dufur	CS, SM,HF	Hill	22.0	19.7	19.8	14.1	19.4
			Lewjain	25.3	19.7	23.2	18.2	18.6
1993	Moro	CR	Stephens	-----	44.2	46.8	44.2	44.8
1993	Pendleton	FR	Madsen	59.5	70.9	66.2	61.3	68.6
			Stephens	69.9	70.5	71.7	68.7	64.0
1994	Arlington	CR	Rohde	----- -	59.2	61.8	61.2	61.0
			Stephens	----	59.0	61.8	57.3	58.5
1994	Helix	CS	Madsen	----- -	55.4	54.6	51.1	51.6
			Rohde	---- --	47.8	49.8	46.5	46.0
			Stephens	---	46.8	47.2	49.8	51.9
1994	Heppner	CS	Madsen	----- -	34.5	30.8	31.8	30.1
			Rohde	---- --	25.0	26.7	24.4	23.9
			Stephens	---	29.1	35.5	31.4	30.2
1994	Moro	CR	Rohde	----- -	45.9	44.5	46.5	48.4
			Stephens	----	45.7	45.9	43.7	45.6
1994	Prosser	CR	Rohde	----- -	55.9	62.4	57.6	48.8
			Weston	----	46.8	53.3	43.7	46.4
1994	Pendleton	FR	Madsen	----- -	93.9	96.7	87.7	99.9
			Stephens	----	95.8	96.9	93.4	101.8

† Yield was constrained primarily by Fusarium root rot (CR), a root disease complex (RR), take-all root rot (TA), strawbreaker foot rot (FR), snow mold (SM), flag smut (FS), dwarf bunt (DB), Cephalosporium stripe (CS), stem rust (SR), Hessian fly (HF), drought (D), or undetectable constraints (N). Disease assessments for 1991-1994 were published in *Fungicide and Nematicide Tests* volumes 47-50 (1992-1995).

Comparison of yields from fungicide-treated and untreated seed indicated (Table 5) that yield of winter wheat was improved more often by Dividend than by Vitavax. Compared to Vitavax, the Dividend treatment (0.5 fl oz/cwt) improved production of wheat by 5 percent (2.7 bu/acre) in 39 comparisons that represented 5 years of testing with 7 varieties at 11 locations. The yield improvement from Dividend was 13 percent (3.0 bu/acre) for areas yielding less than 40 bu/acre and 5 percent(2.7 bu/acre) for areas yielding more than 40 bu/acre (Table 6).

Wheat treated with Dividend at 1 fl oz/cwt yielded slightly more grain than for the 0.5 fl oz/cwt rate, however the response was skewed with respect to the range of productivity expected in the test area. Increasing the Dividend application rate from 0.5 to 1.0 fl oz/cwt increased yield by 4 percent (1.4 bu/acre) in areas yielding less than 50 bu/acre (based on 14 comparisons). In contrast, there was a corresponding

Table 5. Comparison of winter wheat yields in low and high producing areas, as influenced by seed treated with Dividend, Vitavax 200 or RTU Vitavax Thiram, or untreated (combined data from Table 4).

Treatment and rate (fl oz/cwt)	Yield potential where tests were performed		
	< 40 bu/acre	> 40 bu/acre	all areas
Untreated control	23.3	63.2	53.4
Dividend (0.5)	26.1	65.8	56.2
Vitavax (3.0-5.0)	23.1	62.1	53.5
lsd (P=0.05)	2.8	2.4	1.8
Years tested	5	4	5
Locations tested	4	7	11
Varieties tested	6	6	7

Table 6. Relative influence of Dividend or Vitavax (Vitavax 200 or RTU Vitavax Thiram) seed treatments on winter wheat yield and profitability, compared to untreated seed (combined data from Table 4.

Treatment and rate (fl oz/cwt)	Data pairs tested	P > F	Increase in yield		Net profit or <loss>†
			bu/acre	%	$/acre
Dividend (0.25-0.33)	20	0.03	3.2	5.5	$10.32
Dividend (0.5)	44	0.004	2.6	4.8	$ 7.33
Dividend (1.0)	36	0.007	3.1	5.6	$ 7.32
Vitavax (3.0-5.0)	38	0.9	0.1	0.2	<$ 0.92>

† Compared to untreated seed and based on the following criteria: planting rate of 80 lb seed/acre, income of $3.50/bu of grain produced, test weight of 60 lb/bu, and treatment costs of $565.00/gal for Dividend and $32.50/gal for RTU Vitavax Thiram. Calculations were based on Dividend applied at 0.25, 0.5, and 1.0 fl oz/cwt, and RTU Vitavax Thiram applied at 5.0 fl oz/cwt.

Table 7. Emergence[†] of winter wheat seedlings from 3-inch planting depth at two locations during 1993 (seed-zone moisture content was 17.7% at Pendleton and 11.7% at Helix).

Treatment	Days after planting at Pendleton					Days after planting at Helix			
(fl oz/cwt)	8	10	12	14	18	10	12	14	18
Control	1.9	2.8	3.0	3.0	3.0	2.5	2.7	2.9	3.0
Dividend (0.5)	1.6	2.8	3.0	2.9	3.0	2.2	2.7	2.9	3.0
Dividend (1)	1.5	2.2*	3.0	3.0	3.0	2.3	2.9	3.0	3.0
RTU Vitavax Thiram (5)	0.9*	1.5*	2.4*	2.7*	2.9	1.5*	2.5	2.8	2.9
lsd (P=0.05)	0.4	0.4	0.2	0.2	0.2	0.4	0.3	0.3	0.2

[†] Emergence was rated visually as follows; 0 = none, 1 = <10% of seedlings emerged, 2 = 50-85%, 3 = >85%. Combined data for the varieties Madsen and Stephens at Pendleton and Madsen, Rohde and Stephens at Helix. Data within each column differ (P<0.05) from emergence of untreated seed when marked by an asterisk (*).

Table 8. Emergence[†] of winter wheat seedlings from 4- to 5-inch planting depths at Arlington and Prosser during 1993 (seed-zone moisture content was 7.7% at Arlington and 9.1% at Prosser).

	Days after planting at					
	Arlington		Prosser			
Treatment (fl oz/cwt)	15	22	14	21	28	34
Control	2.4	2.9	1.5	2.1	2.1	2.0
Dividend (0.5)	2.8*	3.0	2.2*	2.6*	2.5*	2.6*
Dividend (1)	2.5	2.8	2.2*	2.5	2.1	2.5*
RTU Vitavax Thiram (5)	1.3*	2.5	0.9*	1.5	1.8	1.7
lsd (P=0.05)	0.4	0.4	0.5	0.5	0.4	0.4

[†] Emergence was rated visually as follows; 0 = none, 1 = <10% of seedlings emerged, 2 = 50-85%, 3 = >85%. Combined data for the varieties Rohde and Stephens at Arlington and Rohde and Weston at Prosser. Data within each column differ (P<0.05) from emergence of untreated seed when marked by an asterisk (*).

decrease of 2 percent (1.3 bu/acre) as the Dividend application rate was increased from 0.5 to 1 fl oz/cwt in areas that produce more than 50 bu/acre (22 comparisons).

Winter wheat varieties appeared to differ in yield response to seed treatments (analysis not shown). All varieties had higher mean yields when treated with Dividend compared to untreated seed or Vitavax-treated seed. Compared to Vitavax, Dividend improved yield of Rohde, Stephens, Lewjain, Hill, and Madsen by 0.6, 2.3, 2.4, 4.2, and 4.2 bu/acre, respectively. Compared to untreated seed of these varieties, Dividend increased yield by 2.2, 1.7, 5.1, 5.2, and 0.6 bu/acre, respectively. The numbers of comparisons for each variety were small (5-12), suggesting that these relationships should be considered preliminary until further tests are completed. Fungicide seed treatments did not affect bushel test weights or kernel weights in these experiments (data not presented).

Profitability

At current prices for each fungicide and for wheat produced, the yield data indicated that fungicides applied to provide equivalent levels of protection from smut had very different influences on profitability (Table 6). A net profit was shown for application of Dividend and a net loss for application of Vitavax. It must be stressed that critically important smut-controlling properties of these fungicides were not included in these calculations. Vitavax will continue to serve a highly profitable requirement where it is used preferentially over Dividend. All seed planted in the inland Pacific Northwest must continue to be treated with a smut-controlling fungicide, and the presence of two or more effective fungicides with different active ingredients will provide prolonged assurance for protection in the event that a pathogen develops resistance to one of the fungicides.

Dividend applied at 1 fl oz/cwt yielded slightly more grain than for the 0.5 fl oz/cwt rate but did not increase profitability (Table 6). A closer inspection revealed that the 1.0 fl oz rate increased profitability by \$3.13/acre over the 0.5 fl oz rate in areas of lower production, but reduced profitability by \$2.78/acre in higher production regions.

Profitability was highest for Dividend applied at 0.25-0.33 fl oz/cwt, however, it is not clear that this low rate is sufficient for complete protection from smuts. More experience with these low rates is required before they can be recommended or registered for commercial practice. Region-wide, the 0.5 fl oz/cwt rate of Dividend appears near optimal for controlling smuts and improving profitability.

Seedling Emergence and Development

Differences in emergence rate among fungicide treatments were noted but not quantified during the course of yield trials during 1992. Seedlings emerged from deeply planted seed more rapidly for Dividend than Vitavax treatments. Seedling emergence from Dividend-treated seed was equal to or better than for Vitavax-treated seed in all six experiments conducted during 1993-1994 (Tables 7-9). Dividend was particularly advantageous when seed was planted deeply into warm seedbeds (Tables 7 and 8). Plant height and numbers of tillers or heads per foot of row did not differ among treatments (data not presented).

Table 9. Emergence† of Weston winter wheat seedlings from 5-inch planting depth at Ione and Prosser during 1994 (seed-zone moisture content was 4.9% at Ione and 6.6% at Prosser, and most soft white wheat varieties did not emerge at Ione and were marginally acceptable at Prosser).

	Days after planting							
	Ione				Prosser			
Treatment (fl oz/cwt)	16	23	29	36	13	21	28	34
Control	0	0.4	0.8	0.7	0.8	1.8	2.4	2.8
Dividend (0.5)	0.2	1.0	1.4	1.4*	1.8*	2.2	2.6	2.8
Dividend (1)	0.8*	1.4	2.2*	2.2*	1.6*	2.2	2.6	2.8
RTU Vitavax Thiram (5)	0.8*	1.4	1.6	1.6*	1.6*	2.4	2.6	2.8
lsd (P=0.05)	0.7	ns	0.8	0.7	0.6	0.7	ns	ns

† Emergence was rated visually as follows; 0 = none, 1 = <10% of seedlings emerged, 2 = 50-85%, 3 = >85%. Data within each column differ (P<0.05) from emergence of untreated seed when marked by an asterisk (*).

SUMMARY

Most winter wheat varieties currently recommended in Oregon and Washington are susceptible to dwarf bunt and flag smut, and increasing numbers of varieties susceptible to common bunt are being released. Until more emphasis is placed on developing varieties with resistance to these smuts, fungicide seed treatments will be required to protect winter wheat from infection by the fungi causing these diseases.

Vitavax dominated the seed treatment market for 25 years before Dividend was registered in 1994. This research indicated that Dividend can improve disease management and farm profitability for winter wheat production in the PNW. Dividend (0.5 fl oz/cwt) increased yield 5 percent (2.7 bu/acre) over that from Vitavax-treated seed (5 fl oz/cwt), for an $8.24 increase in net profit per acre. Profitability of Dividend was increased by reducing the application rate to 0.25-0.33 fl oz/cwt, but the efficiency of such low rates for controlling smuts remains unclear. Profitability of Dividend was higher in regions where wheat production is less than 40 bu/acre compared to areas of higher productivity. Emergence of Dividend-treated wheat was as good or better than seed treated with RTU Vitavax Thiram.

This review and research indicated that, by switching from Vitavax to Dividend as the basic smut control fungicide, producers can increase winter wheat yield, profitability, control dwarf bunt, improve seedling emergence from deep seedbeds, and reduce by a factor of ten the amount of fungicide placed into the environment. Dividend achieved about 70 percent (>2.5 million acres) of the market share for a primary seed treatment on winter wheat in the PNW during its first market season (C. Zita, Ciba Crop Protection, personal communication).

Dividend was not tested on spring cereals. Our experience is that fungicide seed treatments are often more effective against diseases of spring than winter cereals (Smiley et al., 1991). Studies should be conducted to determine if yield enhancements from Dividend may be even more important on spring than winter cereals.

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